Channeling quantum information efficiently

To be understood over a crackly telephone line, a person can try to speak more slowly or loudly—or even repeat phrases—to get the message across.

Indeed, noise affects all sorts of communication, whether a radio broadcast or the transmission of bits from one computer to another, and researchers have long sought to determine the most efficient ways of packaging and transmitting information so that it arrives in a form intelligible to the recipient.

The use of photons, electrons, or other quantum particles to carry information represents one potential communication channel. The sender encodes the data as the quantum state of a particle, and the recipient makes a measurement on the particle to infer the original quantum state. The laws of quantum mechanics specify the maximum amount of information that the recipient can extract per particle.

Now, researchers have demonstrated that one can, in principle, approach the theoretical maximum for transmitting information via photons and other quantum particles by carefully choosing how the information is encoded, transmitted, and decoded. The techniques work even when environmental noise distorts the message.

Benjamin W. Schumacher of Kenyon College in Gambier, Ohio, and Michael D. Westmoreland of Denison University in Granville, Ohio, report their findings in the July Physical Review A. In a paper accepted for publication in IEEE Transactions on Information Theory, Alexander S. Holevo of the Steklov Mathematical Institute in Moscow describes his similar analysis.

"These are interesting results," says Charles H. Bennett of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y. Such work "is relevant to communication, precision measurement, and ultimately, perhaps, to quantum computation."

To transmit a string of digits, an apparatus can generate photons whose electric fields vibrate in particular directions. Scientists would like to find the most efficient way to encode those digits.

One possibility is to use many distinct polarization states of a single photon to encode a large number of digits simultaneously. However, quantum mechanics prevents the recipient from reliably distinguishing all those states to convert the quantum information back into digits.

In 1973, Holevo proved a theorem establishing the maximum amount of information a recipient can obtain from a transmitted quantum signal. Last year, Paul Hausladen of the University of Pennsylvania in Philadelphia and his colleagues showed how it was possible to get arbitrarily close to this theoretical limit. The new results from Holevo, Schumacher, and Westmoreland extend those findings to signals distorted by noise—for example, when photons pass through a medium that rotates polarization angles.

In their article, Schumacher and Westmoreland suggest three complementary strategies to get close to the limit. One is to use long strings of photons to send messages in blocks rather than as single photons. The underlying idea is to encode the message in units consisting of a certain number of photons each.

For instance, the sender can encode information in three-photon units. If two different photon polarizations stand for 0 and 1, a set of three photons could encode 000, 001, 010, 011, 100, 101, 110, and 111. Each of these eight combinations, or code words, could represent a particular symbol or letter.

To improve the reliability of decoding, the second strategy is to employ only the most distinguishable of the available quantum states. Thus, it's better to use only the four code words 000, 011, 110, and 101, which differ in two places from each other.

The third technique is to insist that the recipient of a message make a joint measurement on a large number of photons. Measuring three photons at a time, for example, can reveal more information about their quantum states than studying them separately.

Thus, by using long code words (chosen for distinguishability) and an appropriate measurement scheme, it's possible to convey information at any rate up to the Holevo maximum, Schumacher and Westmoreland say.

The findings may give researchers a better sense of how to encode and decode information transmitted via quantum particles and especially how to use as little energy as possible to convey information or even store it in a computer memory. Putting the ideas into practice, however, presents daunting obstacles. For example, making a single measurement on more than two quantum particles at a time remains a formidable task.

The new results from Holevo, Schumacher, and Westmoreland focus on the capacity of quantum channels to carry information expressed in 1s and 0s. Because they can also be prepared in mixed quantum states, photons and other quantum particles can be used to convey information expressed in more complex forms (SN: 4/10/93, p. 229). Such mixtures of states are of particular interest to those exploring the possibility of developing computers that operate according to quantum principles (SN: 1/14/95, p. 30).

"The quantum situation is more complicated," Bennett says. "It's frustrating that we know only parts of the answer yet." *—I. Peterson*

Picky protozoa may sense poison in prey

When a person bites into horseradish, it bites back—producing a stinging sensation that deters many people from taking a second mouthful.

Activities like the chomping action of teeth destroy barriers inside a plant cell that keep certain enzymes and substrates separate. When mixed, these molecules produce chemicals that can protect the plant from being eaten by would-be predators.

Now, researchers report that single-celled organisms may defend themselves in a similar way.

Many types of marine algae produce a substrate called dimethlysulfoniopropionate (DMSP), which is broken down chemically into dimethyl sulfide (DMS) and acrylate by an enzyme called DMSP lyase. This DMS plays a major role in the global sulfur cycle, cloud formation, and possibly climate control. Acrylate is known to be poisonous to microorganisms.

Both DMSP and DMSP lyase reside within algal cells, but the chemical reaction doesn't take place unless a cell is injured—by a hungry predator, for example. Researchers can monitor the amount of algae ingested by a predator in the lab by measuring the amount of DMS that diffuses out of it.

Gordon V. Wolfe, a microbial ecologist at Oregon State University in Corvallis, and his colleagues at the University of Bremen in Germany have found that some protozoa which are sensitive to large amounts of DMSP lyase can survive on algae that make only small amounts of the enzyme. Even protozoa that eat high-enzyme-producing algae prefer the low producers, they report in the June 26 Nature. The researchers suggest that the potential for creating acrylate somehow deters predators.

"The idea that DMSP lyase is a grazing deterrent is really interesting," says Diane Stoecker, a biological oceanographer at the University of Maryland's Horn Point Environmental Laboratory in Cambridge, Md. "DMSP is produced in response to extreme environmental conditions, such as high salt concentrations, but a lot of algae that aren't exposed to extreme conditions produce it too. Until now, there hasn't been a good explanation."

When Wolfe's research team fed a protozoan, *Oxyrrhis marina*, a mixture of low- and high-DMSP lyase-producing algae, they detected little DMS for 24 hours. Then the amounts rose. Wolfe interprets this to mean that the protozoa consumed the low-enzyme producers before attacking the others.

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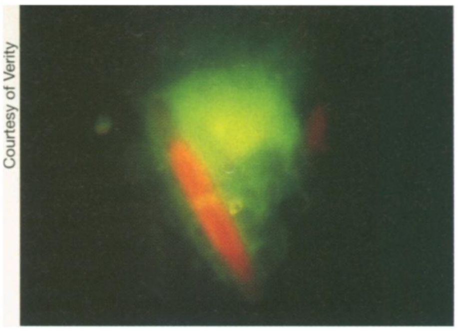
"*Oxyrrhis* is the *Tyrannosaurus rex* of marine protozoa," says Wolfe. "It's voracious. It'll eat almost anything. But even this nonfussy eater prefers food A over food B."

Wolfe cautions that he has not proved that the DMSP lyase reaction underlies the protozoan's food choice. The different algae strains are members of the same species, but they could differ in other ways besides lyase activity. The results do provide a solution to a previously troubling problem: Acrylate is toxic only at extremely high concentrations. Such concentrations, however, could be reached if algae were confined to the small digestive compartments within protozoa.

There are still "major gaps in our understanding," Wolfe said. He wonders how predators know in advance which strains of algae to avoid. The correct choice benefits the high-enzyme-producing algae because, unlike multicellular plants, which can sacrifice small amounts of tissue for the sake of the whole organism, single-celled creatures do not have any cells to spare.

The recent work also contributes to a growing appreciation that protozoa are more sophisticated than previously realized. "Unicellular organisms [like protozoa] are usually thought of as being simple, especially in terms of their behavior," says Peter G. Verity, an ecologist at the Skidaway Institute of Oceanography in Savannah, Ga. "But unicellular does not necessarily equate with simplicity in terms of form or function."



Courtesy of Verity

Protozoan (green) eating an alga (orange).

"A lot of people are building computer models of marine microbial food webs," says Wolfe. "They assume that if a prey is present, a predator will eat it. The models need to be made more sophisticated." —*E. Strauss*

Astronomers get new spin on black holes

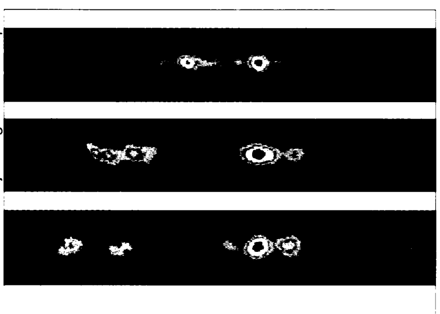
They swallow everything in sight, warp space and time into an unfamiliar tangle, and trap even light in their clutches. Yet for something so complex, black holes are defined by just three properties: mass, charge, and spin.

By studying how ordinary stars are whipped around by their black hole companions, astronomers have measured the mass of many of these dense, invisible objects. Although they have not yet figured out a way to detect charge, scientists now report that they have indirectly determined the spin of several small black holes—those comparable in mass to stars—in the Milky Way.

"Now that we've learned how to measure a second property, spin rate, one might say that we are two-thirds of the way to understanding black holes," says study coauthor Shuang N. Zhang of the Universities Space Research Association at NASA's Marshall Space Flight Center in Huntsville, Ala.

The measurements reveal a specific relationship between the spin of a black hole and the energy it emits as gas is pulled from an orbiting companion onto a disk of material that surrounds and feeds the hole. Some black holes expel jets of material. Black holes with highly energetic jets—those that travel at nearly the speed of light—spin the fastest and in the same direction as the disk, Zhang and his collaborators report in the June 20 ASTROPHYSICAL JOURNAL LETTERS.

The team, which includes Wei Cui of the Massachusetts Institute of Technology and Wan Chen of NASA's Goddard Space Flight Center in Greenbelt, Md., and the University of Maryland at College Park, identified two other indicators of spin. Black holes that emit their highest-intensity radiation at an X-ray energy of 1,000 electronvolts were found to spin rapidly but in a direction opposite to the disk. Holes with X-ray energies that peak at one-fifth to one-tenth that amount spin slowly or not at all. This pattern fits all



R.M. Hjellming and M.P. Rupen

Radio images taken over a week in 1994 show blobs of material ejected at high speed in opposite directions by the black hole GRO J1655-40 (central red spot).

the stellar-mass black holes they've looked at, says Zhang, and may offer new clues about how these exotic beasts form and behave.

To deduce the spin, the astronomers took note of several related properties. A black hole consumes any material that gets closer than a certain distance. This distance, and the spectrum of radiation emitted by infalling material, depends on the black hole's spin.

Using data from four Earth-orbiting spacecraft, the team found the link between spin and X-ray emission. Two of the black holes they examined emit high-speed jets. Both rotate rapidly, and one of them, called GRO J1655-40, spins about 100,000 times per second.

When he heard Zhang present his results at a recent workshop, Mario Livio of the Space Telescope Science Institute in Baltimore got a jolt. In puzzling over the origin of a wide variety of jets in astronomy, Livio had predicted a year ago that black holes that spew such streams must spin rapidly. Unaware of that prediction, Zhang's team validated it. Calling the findings "intriguing but by no means certain," Livio says they provide a new step in deciphering the physics of black holes and jet production. —*R. Cowen*

Genes induce human obesity

In recent years, studies of abnormally hefty rodents have revealed several genetic mutations that induce obesity. Scientists have now found similar mutations in people, although they stress that such genetic flaws are rare.

In the June 26 NATURE, Stephen O'Rahilly of the University of Cambridge in England and his colleagues describe an 8-year-old girl and a 2-year-old boy, cousins and both dangerously obese, who have mutations in the gene for the hormone leptin. Leptin, secreted by fat cells, is thought to govern body weight by sending signals to the brain (SN: 7/29/95, p. 68).

Since finding that mice with mutations in their leptin gene become obese, scientists had unsuccessfully searched thousands of people for similar mutations.

In the July NATURE GENETICS, O'Rahilly's group describes a second obesity-inducing human mutation. They analyzed a woman who had been dangerously obese during her childhood but who has since controlled her weight through dieting. She has a mutant gene for prohormone convertase 1, an enzyme that activates certain proteins, including insulin, as the final step in their production. A similar enzyme is mutated in some obese mice, though how such enzymes influence body weight remains unclear (SN: 6/3/95, p. 341).

"These observations are important not because the etiology of most human obesity has been elucidated—it has not—but because they vindicate an approach to this complex phenotype that emphasizes biology over 'will power' and regards body weight as the result of complex interactions between genes and environment rather than a psychological aberration of free will," comments Rudolph L. Leibel of Rockefeller University in New York in the same issue of NATURE GENETICS. —*J.T.*